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Emission Reduction Technology Assessment for Diesel Backup Generators in California

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is the final report for the "Backup Generators Assessment" project, Contract Number: 500-98-013, conducted by Arthur D. Little. The report is entitled "Emission Reduction Technology Assessment for Diesel Backup Generators in California." This project contributes to the Environmentally-Preferred Advanced Generation program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/pier/reports.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

The present California power crisis is creating an urgent need to look for ways to produce significant amounts of electricity in the near term. Some estimates put the potential short-term power shortage during peak demand periods during the summers of 2001 and 2002 at 5,000 megawatts. A variety of power sources could potentially meet this need, including the current preferred power option of natural gas fired combined cycle power plants. However, the development, certification, and construction of new power plants typically takes a number of years. Although several power plants are currently under construction and measures have been taken to speed the certification process for proposed plants under review, approved and proposed new power plants cannot fill the need during the next two or three years. One option, existing little used diesel backup generators (BUGs), is under consideration as a possible short-term solution for mitigating the number and extent of shortages.

Objectives

The objectives of this project were to:

- Assemble an inventory database containing detailed information on the number, size, type, location, fuel used, age, and emission characteristics of installed BUGs in the state.
- Assess means to mitigate the air emissions associated with increased BUG operation

To support the evaluation of this potential option, one main objective of this project was to assemble an inventory database containing detailed information on the number, size, type, location, fuel used, age, and emission characteristics of installed BUGs in the state. The development of this inventory database is reported separately. The initial database assembled documents nearly 4,100 BUGs with capacity greater than 300 kW totaling about 3,200 MW of aggregate capacity. This database confirms that the overwhelming majority of back-up generators in use employ diesel engines using diesel fuel. Further, most of these engines have no modern emission controls and can be the source of significant amounts of particulate matter (PM) and nitrogen oxide (NO_x) air emissions. Therefore, a second major objective of this project was to assess means to mitigate the air emissions associated with increased BUG operation. Specifically, two approaches were evaluated: alternate, cleaner burning fuels and emissions control technology hardware.

Summary of Emission Reduction Alternatives

A number of alternatives to standard diesel fuel have been or are being developed that offer emissions reduction benefits in diesel engines. Similarly, a number of emissions control technologies for application to diesel engines are in varying stages of development and application. The candidate alternative fuels and emission control technologies considered as potentially applicable in this project included:

Alternative Fuels

- Water Emulsion Diesel Fuels
- Ultra Low Sulfur Content Diesel Fuel
- Synthetic Fuels
- Biofuels

Control Technologies

- Diesel Particulate Filters
- Selective Catalytic Reduction
- Oxidation Catalysts
- Lean NO_x Catalysts
- Timing Retard, Engine Rebuilds
- After-Market Injectors
- Dual Fuel Retrofit Kits
- Fuel Borne Catalysts
- New Generator Sets (Diesel, NG, LPG)

The engine manufacturers, fuel suppliers, and control technology vendors for the above, as well as the California Air Resources Board (ARB) staff, were contacted and requested to supply the most recent performance, cost, and availability data on these fuels and technologies. From this effort a database of information on control approach availability, applicability, effectiveness, costs, and related data was assembled. Due to the variety and number of candidate control approaches listed, each with varying degrees of development status, and differing implementation issues, costs, and cost effectiveness, it was decided to conduct a preliminary screening process so that effort could be focused on technologies with potential for near term applicability. A list of screening criteria was developed and applied to the candidate technology list.

Particulate and NO_x Emission Reduction Options for Near Term Application

This technology screening process identified two alternative fuels and three emission control technologies from the above candidate list that have become sufficiently developed and available for application to diesel BUGs in the state in the time frame of interest. These are:

Alternative fuels

- Water emulsion diesel fuel
- Ultra low sulfur diesel fuel

Control Technologies

- Diesel particulate filter
- Selective catalytic reduction
- Oxidation catalyst

A detailed evaluation of these technologies was then performed. In this detailed evaluation, information received from the diesel engine manufacturers, fuel suppliers, and control technology vendors was organized into tabular summaries. These summaries outline the key aspects of the technologies organized by:

Description and availability

- Emission reduction potential

- ARB Certification status
- Product availability
- Supply / demand effect
- Lead time

Implementation issues

- Compatibility
- Warrantee
- Performance
- Fuel consumption
- Installation
- Maintenance

Control costs

- Cost and cost effectiveness

A summary of the detailed evaluation is as follows:

Alternative Fuels

Water Emulsion Fuels

- Water emulsion fuels are produced by emulsifying deionized water into diesel fuel using a high shear pump. Two suppliers of these fuels are prepared to supply their formulations to segments of the California market beginning this year, Lubrizol with their PuriNOx formulation and Clean Fuel Technology with their A55 formulation.
- Water emulsion fuels reduce diesel engine NO_x emissions by lowering the peak cylinder combustion temperature thereby decreasing the production of thermal NO_x. PM emissions are reduced because the water promotes better fuel atomization.
- ARB has verified PuriNOx at 14 percent NO_x reduction and 63 percent PM reduction. Clean Fuel Technologies claims comparable to better NO_x reduction efficiency and comparable PM reduction efficiency but these claims have not been verified.
- The total amount of water emulsion fuel that could be available this summer to BUG users from the two suppliers is about 22,000 gallons of product per day from blending facilities in Sacramento and Reno, Nevada. This compares to an average of 32,000 gal / day needed to operate 500 MW of BUG capacity for 104 hours over the four-month summer period of June through September.
- The use of water emulsion fuels can pose a major issue for BUG operators because these fuels have a lower energy content (Btu / gal) than conventional diesel. This can lead to a 5 to 15 percent loss in maximum power in a BUG using water emulsion fuel.
- Water emulsion fuels provide the most cost effective ($ / ton) NO_x and PM emission reductions of the emission reduction approaches evaluated.

Ultra Low Sulfur Diesel

- Two suppliers in the state are currently offering ultra low sulfur diesel fuel with sulfur content of 15 ppm, Arco-BP from its refineries in Richmond and Los Angeles, and Shell-Equilon from its refinery in Martinez. This compares to the sulfur content of diesel fuel currently sold in the state of 140 to 150 ppm. The 1,000,000-gal/day supply capacity each refiner has established will be sufficient to fuel all the BUGs in the state as well all other sources of expected demand for this product for both this summer and the next.
- Although ultra low sulfur diesel provides only small direct reductions in NO_x and PM emissions (0 and 10 percent, respectively) it is viewed as an enabling technology that allows the use of diesel particulate filters to provide more significant PM reductions.
- For PM reductions, ultra low sulfur diesel has cost effectiveness comparable to that of water emulsion fuels, though PM reductions are less significant.

Control Technologies

Diesel Particulate Filters

- Two suppliers offer DPFs that can achieve substantial PM reductions in the 85 to 90 percent range, Englehard and Johnson Matthey.
- Both suppliers' offerings have been verified by ARB at 85 percent reduction for select diesel engine families in onroad applications. Both verifications require the use of ultra low sulfur diesel fuel.
- Both vendors could supply up to 1,000 units with lead times that range from four to eight weeks.
- DPFs will introduce some back pressure in a BUG's exhaust system. Accordingly, both suppliers custom engineer each application to ensure total back pressure does not exceed engine specifications.
- DPFs offer less cost effective PM reductions than water emulsion fuels, though reductions are more significant.

Selective Catalytic Reduction

- Five suppliers offer SCR systems for use on diesel engines. Of these, four use urea as the NO_x reducing agent; the fifth uses ammonia. All suppliers offer systems that can achieve 90 to 95 percent NO_x reductions with maximum ammonia slip of 10 ppm. Two systems offer PM reductions as well.
- Over 500 urea-based SCR systems could be made available for installation during 2001 with lead times of 8 to 12 weeks. This increases to over 1,000 systems in 2002 with the same lead time range.
- The cost effectiveness of most SCR processes for NO_x reduction is not significantly higher than that for water emulsion fuels and greater NO_x reductions are achieved.

Oxidation Catalysts

- Oxidation catalysts designed to reduce CO and vapor phase hydrocarbons emissions also offer some PM reduction by promoting particulate carbon burnout. Both DPF vendors offer very similar oxidation catalyst products that are designed to operate with conventional diesel fuel and provide modest decreases in PM emissions of 20 to 30 percent.

- One vendor, Johnson Matthey, also offers a variation of its product that can provide greater PM emissions reductions in the 30 to 50 percent range. This catalyst formulation requires the use of diesel fuel with a maximum sulfur content of 50 ppm, and is recommended for use in 2-stroke and older, dirtier engines instead of DPFs.
- All of the available oxidation catalysts have lead times of between 2 and 12 weeks, with the longer lead times applying to larger size orders such as 500 to 1,000 units.
- Oxidation catalysts generally offer less cost effective PM control than DPFs.

Conclusions

One possible option being considered to minimize forecasted power outages in California during the summers of 2001 and 2002 is to employ the BUG capacity installed in the state when power outages are imminent. As most of this capacity is diesel engine driven, with significantly greater emissions of NO_x and PM on a lb/MWh than any other power generation technology, the potential air quality impacts of BUG use could be significant.

The use of diesel BUGs would have less serious air quality impacts if emission controls were utilized. In this project, candidate NO_x and PM emission control options were screened to identify those with potential for near term application. Control options identified as being sufficiently developed and demonstrated to be available for near term application were subjected to detailed evaluation to establish their applicability, availability, costs, and cost effectiveness, and to identify such implementation issues as effects on BUG operation, performance, maintenance needs, and fuel consumption.

Two alternative fuels and three emissions control technologies were identified as being available for near term application. Emission reductions offered by these control options are:

Alternative fuels

- Water emulsion fuels
  - 14 to 22 percent NO_x reduction
  - 25 to 63 percent PM reduction
- Ultra low sulfur diesel fuels
  - 10 percent PM reduction

Control Technologies

- Diesel particulate filters (which may require the use of ultra low sulfur diesel fuel)
  - 85 to 90 percent PM reduction
- Selective catalytic reduction
  - 70 to 95 percent NO_x reduction
- Oxidation catalysts
  - 20 to 50 percent PM reductions (the higher percent reductions require the use of ultra low sulfur diesel fuel)

Water emulsion fuels offer the most cost effective NO_x reductions. For PM reductions alone, ultra low sulfur diesel has cost effectiveness comparable to that of water emulsion fuels, though PM reductions are less significant. Both these fuels could be in use during 2001. One particular drawback of water emulsion fuels, however, is the 5 to 15 percent power loss associated with their use.

Given lead-time considerations, retrofit control technologies would likely not be able to affect summer 2001 emissions, but could be in place for 2002. These technologies can offer more substantial emission reductions, but are also more costly such that their cost effectiveness measures are higher than those for the alternative fuels.

Benefits to California

This study documents the availability, effectiveness, and costs of several alternative fuels and emission control technologies that can be employed by diesel BUGs in the near term to reduce their air emissions. These emission reduction technologies can be used to mitigate the adverse air quality impacts of increased BUG use to reduce the number and extent of future power shortages such as those experienced in California in 2000 and early 2001. Potential BUG deployment programs to offset power shortages can, thus, be defined to require the use of various combinations of the technologies such that air quality effects are minimized, with the costs and effectiveness of these requirements known. At this time, it seems unlikely BUGs will be used to offset power shortages. However, this information can be used to make informed decisions regarding approaches to reducing emissions from diesel engines and associated air quality impacts.

Abstract

One option under consideration as a possible short-term solution to mitigating the number or extent of power shortages forecast during the present California power crisis is making use of the backup generator (BUG) capacity installed in the state. However, because most of this capacity is diesel engine driven, with significantly greater emissions of NO_x and PM on a lb/MWh basis than any other power generation technology, the potential air quality impacts of its use could be significant.

In this project, candidate NO_x and PM emission control options were screened to identify those with potential for near term application to mitigate the impacts of diesel BUG use. Control options identified as being sufficiently developed and demonstrated to be available for near term application were subjected to detailed evaluation to establish their applicability, availability, costs, and cost effectiveness, and to identify such implementation issues as effects on BUG operation, performance, maintenance needs, and fuel consumption.

The control approach screening identified two alternative fuels, water emulsion fuels and ultra low sulfur diesel, and three emissions control technologies, diesel particulate filters, selective catalytic reduction, and oxidation catalysts, as being available for near term application. Results of the detailed evaluations are presented in the report.

1.0 Introduction

The present California power crisis is creating an urgent need to look for ways to produce significant amounts of electricity in the near term. Some estimates put the potential short-term power shortage during peak demand periods during the summers of 2001 and 2002 at 5,000 megawatts. A variety of power sources could potentially meet this need, including the current preferred power option of natural gas fired combined cycle power plants. However, development, certification, and construction of new power plants typically takes a number of years. Although several power plants are currently under construction and measures have been taken to speed the certification process for proposed plants under review, approved and proposed new power plants cannot fill the need during the next two or three years. One option, existing little used diesel backup generators (BUGs), is under consideration as a possible short-term solution for mitigating the number and extent of shortages.

To support the evaluation of this potential option, one main objective of this project was to assemble an inventory database containing detailed information on the number, size, type, location, fuel used, age, and emission characteristics of installed BUGs in the state. Once such a database is assembled, it would be a simple matter to estimate the total number and capacity of BUGs for the state, by region, or any other characteristic documented in the database.

This inventory database development effort, reported separately, identified nearly 4,100 BUGs in the state with capacity of at least 300 kW. The aggregate capacity of these units totaled over 3,200 MW. The inventory confirmed that approximately 85 percent (nearly 3,500) of the installed BUGs, comprising about 84 percent (over 2,700 MW) of the generating capacity, were diesel-fueled diesel (compression ignition) engine-driven units.

Diesel engine-powered BUGs have substantially greater emissions of NO_x and particulate (PM) than any other power generation technology, when measured on a lb / MWh basis. For example, California Air Resources Board (ARB) estimates of the emission rates of these two pollutants on this basis for several power generation technologies are given in Table 1. As indicated in the table, existing diesel BUG NO_x emissions are a factor of 25 to 60 times greater than from current new gas-fired simple cycle gas turbine peaking units, a factor of 50 to 60 times greater than from the existing California mix of gas-fired power plants, and a factor of 500 to 600 times greater than from new gas-fired combined cycle power plants with selective catalytic reduction (SCR). Similarly, existing diesel-fueled diesel BUG PM emissions are 15 to 100 times greater than from gas-fired power generation processes.

Table 1. NO_x and PM Emissions from Select Electricity Generation Technologies

Technology	Emission Factor[a] lb/MWh
NO_x Emissions7	
Existing diesel-fueled diesel engine BUGs	25 to 30
New gas-fired simple cycle gas turbine without SCR	0.5 to 1
Typical mix of California gas-fired power plants	0.5
New gas-fired combined cycle power plant with SCR	0.05
PM Emissions	
Existing diesel-fueled diesel engine BUGs	1 to 3
Gas-fired power generation	0.03 to 0.07

[a]Letter from Michael P. Kenny, Executive Officer, ARB, to Air Pollution Control Officers, February 21, 2001.

The high diesel BUG emission factors represent a concern because NO_x is an ozone precursor, and many areas in the state are in nonattainment of the California ambient air quality standard for ozone. Diesel PM emissions are a concern because ARB has declared diesel PM to be a toxic air contaminant because of its carcinogenic characteristics.

Given the substantially greater emissions from diesel BUGs compared to other power generation technologies, a second major objective of this project was to identify and evaluate potential means to reduce NO_x and PM emissions from diesel BUG operation. The primary focus was to identify emission reduction approaches that could be employed in the near term, specifically during the summers of 2001 and 2002 when the need for supplemental power supplies in the state is expected to be the greatest. Two categories of approaches were evaluated: alternate cleaner burning fuels and emissions control technology hardware.

The assessment was initiated by identifying all emission control approaches, both alternative cleaner burning fuels as well as engine modification and exhaust gas treatment technologies, that have been developed for or applied to diesel engines. These approaches were then screened for effectiveness and development status. Those sufficiently developed and available that they could be implemented to some extent before the summer of 2002 were identified. These selected approaches were then subjected to detailed evaluation that included the assessment of near term availability, implementation issues, control effectiveness, and costs and cost effectiveness.

Results of the evaluation are presented in the following sections. Section 2 lists all the control approaches considered, outlines the screening criteria used to assess near-term applicability, and identifies those approaches that were not selected for detailed evaluation. Results of the detailed evaluation of selected approaches are presented in Section 3. Section 4 summarizes evaluation conclusions.

In an attempt to place the need for diesel BUG emission control into perspective if these are to see more widespread use to mitigate near-term power supply shortfalls, an analysis of the potential impact of increased diesel BUG use on regional emissions inventories was performed. Appendix I provide the results of this analysis, which shows potentially significant NO_x emissions impacts in some APCD / AQMDs.

2.0 Summary of Emission Reduction Alternatives

A number of alternatives to standard diesel fuel have been or are being developed that offer emissions reduction benefits in diesel engines. Similarly, a number of emissions control technologies for application to diesel engines are in varying stages of development and application. The candidate alternative fuels and emission control technologies considered as potentially applicable in this project are listed in Table 2. This list also includes the option of replacing an existing, older diesel BUG with a new generator powered by a new, certified, lower emission diesel engine. Also included was the option for a natural gas or propane (LPG) fueled engine, as this also gives an emissions benefit.

The engine manufacturers, fuel suppliers, and control technology vendors also listed in Table 2 were contacted and requested to supply the most recent performance, cost, and availability data on these fuels and technologies. ARB staff was also contacted for any information they had, particularly with regard to ARB certification, status, and data. From this effort a database of information on control approach availability, applicability, effectiveness, costs, and related data was assembled.

Due to the variety and number of candidate control approaches listed, each with varying degrees of development status, and differing implementation issues, costs, and cost effectiveness, it was decided to conduct a preliminary screening process so that effort could be focused on technologies with potential for the near term applicability of interest in this project. A list of screening criteria was developed and applied to the candidate technology list. These screening criteria are discussed in Section 2.1. The technologies from Table 2 that were rejected from further consideration in the project are briefly discussed in Section 2.2.

2.1. Assessment Criteria

The technology screening criteria to evaluate alternative approaches consisted of the following:

- **Emission Reduction Potential:** What is the technology's NO_x and / or PM emissions reduction effectiveness?

- **Warranty:** Will the use of the technology effect the warranty of the original equipment manufacturer of the BUG? What are the terms of the warranty provided by the technology provider?

- **Compatibility:** Are there any types, designs, or applications of BUG models that the technology is not compatible with?

Table 2. Emission Reduction Technology Providers Contacted

Technology	Technology Provider
Alternative Fuels	
Water Emulsion Diesel Fuels	Lubrizol Clean Fuel Technology (A-55)
Ultra Low Sulfur Content Diesel Fuel	ARCO-BP Shell-Equilon
Synthetic Fuels	Syntroleum Shell
Biofuels	World Energy Alternatives Ag Environmental Products
Control Technologies	
Diesel Particulate Filters	Engelhard Johnson Matthey
Selective Catalytic Reduction	Engelhard Johnson Matthey Siemens Kleen-Air Clean Diesel Technologies
Oxidation Catalysts	Engelhard Johnson Matthey
Lean NO_x Catalysts	Ceryx
Timing Retard, Engine Rebuilds	Caterpillar Cummins Detroit Diesel
After-Market Injectors	Interstate McBee
Dual Fuel Retrofit Kits	Cambian Energy VESI
Fuel Borne Catalysts	Clean Diesel Technologies
New Generator Sets (Diesel, NG, LPG)	Caterpillar Cummins Detroit Diesel

- **ARB Certification/Permitting Status:** Are the emission reduction claims of the technology vendor certified / verified by ARB? If not, is the technology permitted for use in demonstrations in California? Has a non-tampering exemption been issued?

- **Product Availability:** What is the maximum demand that the existing providers can provide for the summers of 2001 and 2002?

- **Supply/Demand Effect:** Would any price reductions be achievable with increased sales volume? Conversely, would price increases occur in the event of increased demand due to BUG use; this is of particular concern for alternative fuels.

- **Performance:** Will the technology have any effect on the BUG's usual operating characteristics or power output?

- **Fuel Consumption:** Will the technology have any effect on the BUG's fuel consumption?

- **Cost Effectiveness:** What is the cost per ton of NO_x or PM reduced annually? Cost includes the installed cost of the control technology and any incremental operating costs.

- **Lead Time:** How much time is required to put the alternative fuel or technology into operation after placing a purchase order?

- **Installation:** Are there any special installation requirements for the technology, such as ancillary equipment or infrastructure hardware? How will installation requirements and costs vary with different BUG models and types?

- **Maintenance:** What new maintenance procedures or costs will be involved with the use of the technology?

- **Other Implementation Issues:** Are there any other issues related to deploying the technology that are not covered in the above criteria?

2.2. Alternative Fuels and Retrofit Technologies Not Selected for Detailed Evaluation

After applying the above assessment criteria, many of the control approaches listed in Table 2 deemed not viable candidates for near term application and were, thus, not subject to further detailed evaluation. Reasons for their removal from further consideration are outlined below.

2.2.1. Alternative Fuels

2.2.1.1. Synthetic Fuels

These fuels would not be available in sufficient quantities to support any significant BUG usage. Current vendors of these fuels are not planning significant domestic production capability for two to three years. Further, costs for these fuels are high, at about $0.30/gal above that of conventional diesel fuel sold in California.

2.2.1.2. Biofuels

These fuels would also not be available in sufficient quantities to support any significant BUG usage, except perhaps in a few niche applications, and their costs are also high. Moreover, while they offer PM reductions, NO_x emissions increase with their use.

2.2.2. Control Technologies

2.2.2.1. Lean NO_x Catalysts

The emissions reduction capabilities of this technology have not been sufficiently demonstrated.

2.2.2.2. Fuel Borne Catalysts

These products were not considered a viable option because they may produce potentially toxic metal-containing particulate emissions. These toxicity and air quality issues also raised the issue of whether these additives would be legal for use in BUGs in California. Given these issues, the use of these products did not seem justified given the relatively small emissions reductions that they could offer.

2.2.2.3. After-Market Fuel Injectors

This technology is only readily available for a very limited number of smaller BUG makes and models.

2.2.2.4. Timing Retard

This option would only be applicable to a very limited number of BUGs. It would not be an option for electronically injected engine models, and most mechanically injected models in the state employed timing retard at the time of their original permitting. Further, on those few mechanical models that do not already employ timing retard, the approach has the undesired effect of increasing PM emissions by as much as 80 percent.

2.2.2.5. Dual Fuel Retrofit Kits

This technology has not been sufficiently demonstrated in BUG applications. Moreover, installation of these kits could also involve very high initial costs for the kit purchase and its installation, especially if new natural gas fuel lines to the operating facility are required.

2.2.2.6. Engine Rebuilds

Rebuilding an existing BUG's diesel engine would generally only restore the unit to its original emissions levels. This would not likely provide a very significant decrease in emissions, and has a high cost (e.g., $50,000 for an 800 kW 2-stroke engine).

2.2.2.7. New Generator Sets (Diesel, NG, LPG)

While the purchase of new generator sets could in some situations provide significant emissions reductions compared to a baseline diesel BUG, this option was eliminated primarily because of its very high cost. For example, a new diesel generator set costs about $200,000 for a 1 MW unit; natural gas units of the same power output cost about $450,000.

3.0 Particulate and NO_x Emission Reduction Options for Near Term Application

The technology screening process discussed in Section 2 identified two alternative fuels and three emission control technologies that have become sufficiently developed and available for application to diesel BUGs in the state in the time frame of interest. These are:

Alternative fuels

- Water emulsion diesel fuel
- Ultra low sulfur diesel fuel

Control Technologies

- Diesel particulate filter
- Selective catalytic reduction
- Oxidation catalyst

In the detailed evaluation of these technologies, information received from the diesel engine manufacturers, fuel suppliers, and control technology vendors was organized into tabular summaries. These summaries outline the key aspects of the technologies in terms of the assessment criteria discussed in Section 2.1. These assessment criteria were grouped into three topical areas as follows:

Description and availability

- Emission reduction potential
- ARB Certification status
- Product availability
- Supply / demand effect
- Lead time

Implementation issues

- Compatibility
- Warrantee
- Performance
- Fuel consumption
- Installation
- Maintenance

Control costs

- Cost and cost effectiveness

Summary information on the emission reduction approaches included in the detailed evaluation in each of these topical areas is given in Table 3 through Table 5.. The summary information contained in Table 3 and Table 4. is elaborated in Section 3.1 below. Section 3.2 discusses the control cost and effectiveness data summarized in Table 5..

Table 3. Emission Reduction Option Description and Availability

Technology	Description	Provider/ Product	Product Characteristic	Emission Reduction Potential, %		ARB Certification Status	Product Availability[c]	Supply/Demand Effect	Lead Time
				NO_x	PM				
Alternative Fuels									
Water Emulsion Fuel	• Blend of diesel, water, and stabilizing additives • Lowers peak combustion temperature and reduces NO_x and PM formation	Lubrizol/PuriNOx	• 17% water deionized water by volume	14%[a]	63%[a]	• Verified for heavy-duty diesel onroad engines at 14% NO_x reduction and 63% PM reduction	• Currently: 6,000 gal/day for Sacto/Bay Area for new customers • July/Aug 2001: up to 12,000 gal/day in Sacto/Bay Area for new customers • Summer 2002: 48,000 gal/day statewide	• Can supply demand in S. CA by July 2001 if demand committed • S. CA local mixer/distributor needed to meet demand at prices similar to Sacto • 7,700 gal min orders reduces price to $0.07-$0.10 more per gallon plus freight charges • Freight charges from Sacto mixer/distributor: Sacto: no charge Bay Area: $0.07/gallon LA: $0.14/gallon	• N. CA - no lead time • S. CA - Now with freight charge from Sacto distributor, or from LA based mixer/distributor as early as July if permits expedited and demand committed
		Clean Fuel Technology/A55	• 13% water by volume	• Up to 15-22% for newer engines[b] • Up to 50% for older engines[b]	25-50%[b]	• Not certified/verified	• Current output: 16,000 gal/day from Reno • Summer 2002: up to 100,000 gal/day if demand committed • Available to Sacto/Bay Area in 8,000 gal orders (no local distributor)	• Costs can drop 25% if CA local mixers established to eliminate transport costs from Reno • No local distributors established yet to handle orders smaller than 8,000 gal, could be established to meet demand	

Technology	Description	Provider/ Product	Product Characteristic	Emission Reduction Potential, % NOx	PM	ARB Certification Status	Product Availability[c]	Supply/Demand Effect	Lead Time
Alternative Fuels									
									• 1-2 months to meet volume above 16,000 gal/day and supply to S. CA
Ultra Low Sulfur Diesel	• Diesel with sulfur content lower than 15 ppm • CA diesel contains an average 140-150 ppm • Considered to be an enabling technology that permits the use of diesel particulate filters	Arco-BP/ECD-1	• 15 ppm sulfur content • Similar aromatic level to ARB diesel	No effect	10%	• Not certified/verified • Experimental Permit issued by ARB • Legal for sale and use in CA	• 1 million gal/day maximum available statewide from LA and Richmond refinery • Sufficient supply for over 1,000 MW of BUGs statewide	• Summer 2001 statewide demand (without BUGs): 125,000 gal/day • Summer 2002 expected demand (without BUGs): 275,000 gal/day • Costs can drop 25 to 40% in Sacto/San Diego by summer 2002 with increased demand	• July 2001- available in major CA cites for small size orders through local distributors
		Shell-Equilon	• 15 ppm sulfur content	No effect	10%	• Not certified/verified • Experimental Permit issued by ARB • Legal for sale and use in CA • Used in New York MTA demonstrations	• 1 million gal/day maximum available statewide from Martinez refinery • No current delivery infrastructure established to deliver small orders (500-2,000 gallons) • Sufficient supply for over 1,000 MW of BUGs statewide	• Current statewide demand: <5,000 gal/day (only current customer is State for 500-1,000 gal orders) • Summer 2002: expected increases in demand for transit and school busses would be small percentage of total production capacity	• Currently available from Martinez refinery with premium price for cost of delivering small orders (500-2,000 gal) by truck

[a] ARB verified
[b] Vendor claim
[c] California's current diesel demand is estimated by the Energy Commission to be between 2.25 and 3 billion gallons/year (7.5 to 8 million gallons/day)

Table 3. Emission Reduction Option Description and Availability (Continued)

Technology	Description	Providers/ Product	Product Characteristic	Emission Reduction Potential, % NOx	Emission Reduction Potential, % PM	ARB Certification Status	Product Availability[a]	Supply/Demand Effect	Lead Time
Diesel Control Technologies									
Diesel Particulate Filter	• Physically trap and collect diesel PM • ARB verification requires diesel fuel with maximum 15 ppm sulfur	Engelhard/ DPX Soot Filter	• Catalyzed filter combining precious metal catalyst and ceramic soot filter to reduce PM, HC, and CO	No effect	85%	• Verified at 85% PM reduction in 1995 through 2001 Cummins 10.8L onroad engines • Received non-tampering exemption	• No data	• No data	• 4-8 weeks
		Johnson Matthey/ CRT	• Composed of two chambers: a platinum-coated oxidation catalyst and a particulate filter • Oxidizing agent produced in oxidation catalyst is used for regeneration	No effect	85%	• Verified at 85% PM reduction in 1998 through 2000 Detroit Diesel 50/60 Series onroad engines • Received non-tampering exemption	• Summer 2001: 2,000 units max • Summer 2002: 10,000 units	• Unspecified decrease in parts cost with 500-1,000 units demanded	• 6-8 weeks
Selective Catalytic Reduction	• Ammonia or urea reduce NO_x to N_2 in presence of a catalyst	Engelhard/ SCR	• Urea as reductant	95%	No effect	• Not certified/verified	• No data	• No data	16-20 weeks
		Johnson Matthey/ Urea SCR	• Urea as reductant • Does not require compressed air for urea injection as some other SCR systems	90%	No effect	• Not certified/verified	• Summer 2001: 12 units max	• 500 unit order filled at 30% lower parts cost	• 12 weeks for small orders (<500 units) • 24 weeks for larger orders (500 units and more)
		Siemens	• Urea as reductant (33% solution) • VTT catalyst offers lower ammonia slip and some PM reduction	90-95%	20-30%	• Not certified/verified	• Summer 2001: 500 units • Summer 2002: 1,000 units	• Costs can drop 20% with increased demand	• 8 weeks

Technology	Description	Providers/ Product	Product Characteristic	Emission Reduction Potential, %		ARB Certification Status	Product Availability[a]	Supply/Demand Effect	Lead Time
				NO_x	PM				
					Diesel Control Technologies				
		Kleen Air	• Ammonia as reductant • System includes oxidation catalyst for CO, HC, and PM reduction	80-90%	50-70%	• Not certified/verified	• No units available Summer 2001 • Summer 2002: 500 units	• 10-20% reduction on parts cost if 500-1,000 units demanded	• 9-12 months
		Clean Diesel Technologies	• Urea as reductant • Higher end of NO_x reductions available with increased catalyst size and increased cost	70-95%	No effect	• Not certified/verified	• Summer 2001: 20-30 units	• Increased demand will not lower costs	• Summer 2001: 8-12 weeks • Summer 2002: 6-8 weeks
Oxidation Catalyst	• Catalytic oxidation lowers HC, CO , and PM emissions	Engelhard/ GEN	• Designed primarily for HC and CO control • Designed for 500 ppm and lower sulfur diesel	No effect	30%	• Not certified/verified as a retrofit • Some diesel engines are certified with oxidation catalysts as original emission control equipment	• No data	• No data	• 2-4 weeks
		Johnson Matthey/ DOC	• Designed for 500 ppm and lower sulfur diesel	No effect	20%	• Not certified/verified as a retrofit • Some diesel engines are certified with oxidation catalysts as original emission control equipment	• Summer 2001: 400 units max • Summer 2002: 500-1,000 units	• 500-1,000 unit order = 15% reduction in parts cost	• 4-8 weeks for small orders • 4-12 weeks for orders of 400-1,000 units
		Johnson Matthey/ RCO	• Requires 50 ppm sulfur maximum diesel • Contains substantially more platinum than other oxidation catalysts	No effect	30-50%	• Not certified/verified as a retrofit • Some diesel engines are certified with oxidation catalysts as original emission control equipment	• Summer 2001: 400 units max • Summer 2002: 500-1,000 units	• 500-1,000 unit order = 15% reduction in parts cost	• 4-8 weeks for small orders • 4-12 weeks for orders of 500-1,000 units

[a] California's current diesel demand is estimated by the Energy Commission to be between 2.25 and 3 billion gallons/year (7.5 to 8 million gallons/day)

Table 4. Emission Reduction Option Implementation Issues

Technology	Providers/ Product	Compatibility	Warranty	Performance	Fuel Consumption	Installation	Maintenance
Alternative Fuels							
Water Emulsion Fuel	Lubrizol/ PuriNOx	• Can be used on all heavy duty diesel engines • Some mechanically injected engines may be able to be modified for increased fuel use (gal/hour)[a] • Most electronically injected engines cannot be easily reprogrammed for increased fuel use; these engines will not be able to produce maximum power output via increased fuel use[a] • Effects on engine durability may be a concern	• No effect on OEM warranty	• 13-15% power loss without fuel use (gal/hr) increase	• No change in fuel use (gal/hr) with power loss • Increase in fuel use (gal/MWhr) with no power loss • Power loss may be avoided on some models that can increase fuel injection quantity. In those cases, tradeoff between fuel consumption and power loss	• Manufacturers recommend low-volume fuel circulation pump o fuel storage tank • Facility specific potential need for segregated storage	• Without pump shelf life 2 months, with pump 8-9 months
	Clean Fuel Technology/ A55		• No effect on OEM warranty	• 5-9% power loss without fuel use (gal/hr) increase			
Ultra Low Sulfur Diesel	Arco-BP/ECD-1	• Can be used on all heavy duty diesel engines	• No effect on OEM warranty	No effect	No effect	• Facility specific potential need for segregated storage	• No increased maintenance
	Shell-Equilon		• No effect on OEM warranty	No effect	No effect		

[a] The overwhelming majority of diesel engines manufactured since 1990 use electronically controlled injection; the ability to recover 5 to 15% power loss due to decreased fuel heat content will be problematic in these engines.

Table 4. Emission Reduction Option Implementation Issues (Continued)

Technology	Provider/ Product	Compatibility	Warranty	Performance	Fuel Consumption	Installation	Maintenance
Diesel Control Technologies							
Diesel Particulate Filter	Engelhard/ DPX Soot Filter	• Regeneration requires a 700°F temperature for 25% of the operation time • Not recommended for 2-stroke engines because exhaust temperatures too low when not at full load • Designed for 150 ppm sulfur diesel and lower (emissions based on 150 ppm level)	• No effect on OEM warranty • 1 year manufacturer warranty	• Claimed emission reduction levels achievable with 150 ppm sulfur diesel	• No effect, designed to application's back pressure limit specifications, thus no effect on power or efficiency	• Each installation is custom designed • Engineering and equipment installation included in quoted cost	• Inspect, clean filter, and reverse, every 1,500-2,000 hrs ($200 max cost) • Cost negligible for BUGs as maintenance interval greater than average BUG life
	Johnson Matthey/ CRT	• Requires a maximum of 50 ppm sulfur diesel for reliable regeneration • Not recommended for 2-stroke engines because exhaust temperatures too low when not at full load	• Not likely to effect OEM warranty • Manufacturer warranty is offered	• 50 ppm sulfur diesel required	• 0-2% increase in fuel consumption		• One hour of maintenance 1-2 times/yr, vacuuming and cleaning of filter with shop vac and compressed air ($100 max cost)

Table 4. Emission Reduction Option Implementation Issues (Continued)

Technology	Provider/ Product	Compatibility	Warranty	Performance	Fuel Consumption	Installation	Maintenance
Diesel Control Technologies (continued)							
Selective Catalytic Reduction	Engelhard/ SCR	• Typical engine operating temperatures are sufficient • Available for most CAT, Cummins and Detroit Diesel models • Space limitations due to large size of unit	• No effect on OEM warranty • 2 year 1,600 hr manufacturer warranty	• Custom designed to match product to BUG back pressure specification limits to avoid any loss of power • No SCR issues with manual start up of BUGs	• With no additional back pressure, no effect on fuel consumption • Models with 4-degree timing retard can improve fuel consumption 4-6% by setting timing back to 0 degrees giving a reduction in PM. Local air districts will determine if timing adjustment is allowed under each BUGs'	• Each installation is custom designed • Engineering and equipment installation included in quoted cost	• Occasionally inspect and replace catalyst (no cost data) • Catalyst replacement needed at intervals greater than average BUG life
	Johnson Matthey/ Urea SCR	• 600-800 °F operating temperature • Space limitations due to large size of unit	• Effect on OEM warranty uncertain • 5 year 10,000 hr manufacturer warranty	• SCR system designed to come on automatically after start-up once engine reaches min. required operating temperature • Custom designed to match product to BUG back pressure specification limits to avoid any loss of power • No SCR issues with manual start up of BUGs			• Inspect catalyst every 6 months, vacuum/clean as needed (8 hrs labor each inspection, or $1,600/yr) • Catalyst replacement needed at intervals greater than average BUG life

Technology	Provider/ Product	Compatibility	Warranty	Performance	Fuel Consumption	Installation	Maintenance
Diesel Control Technologies (continued)							
	Siemens	• 500-900 °F operating temperature • Available for most CAT, Cummins and Detroit Diesel models • 2-stroke engine SCR more expensive • Space limitations due to large size of unit	• No effect on OEM warranty • 1 year manufacturer warranty	• SCR system designed to come on automatically after start-up once engine reaches min. required operating temperature • Custom designed to match product to BUG back pressure specification limits to avoid any loss of power • No SCR issues with manual start up of BUGs	permit limitations		• Inspection by technician required twice a year (8 hrs labor each inspection, or $1,600/yr) • Catalyst replacement needed at intervals greater than average BUG life
	Kleen Air	• 300 °F minimum operating temperature • Space limitations due to large size of unit	• No expected effect on OEM warranty • Manufacturer warranty is offered	• Custom designed to match product to BUG back pressure specification limits to avoid any loss of power • No SCR issues with manual start up of BUGs • No N_2O emissions since ammonia used instead of urea			• Inspection by technician required twice a year (8 hrs labor each inspection, or $1,600/yr) • Catalyst replacement needed at intervals greater than average BUG life
	Clean Diesel Technologies	• 500-900 °F operating temperature • Space limitations due to large size of unit	• No effect on OEM warranty • 2 year 8,000 hr warranty	• SCR system designed to come on automatically after start-up once engine reaches min. required operating temperature • Custom designed to match product to BUG back pressure specification limits to avoid any loss of power • No SCR issues with manual start up of BUGs			• Inspection by technician required (2 hr/yr, $400 cost) • Catalyst replacement needed at intervals greater than average BUG life

Table 4. Emission Reduction Option Implementation Issues (Continued)

Technology	Provider/ Product	Compatibility	Warranty	Performance	Fuel Consumption	Installation	Maintenance
Diesel Control Technologies (continued)							
Oxidation Catalyst	Engelhard/ GEN	• 400-500 °F operating temperature for best efficiency • No restriction on type or make of engine	• No effect on OEM warranty • 1 year manufacturer warranty	No effect	• No effect, designed to application specifications for no additional back pressure	• Each installation is custom designed • Engineering and equipment installation included in quoted cost	• No increased maintenance
	Johnson Matthey/ DOC	• 300°F operating temperature • No restriction on type or make of engine	• No effect on OEM warranty • Manufacturer warranty is offered	No effect	• 1% increase in fuel consumption		• Clean unit every 15,000 hrs ($1,000 cost) • Cost negligible for BUGs as maintenance interval greater than average BUG life
	Johnson Matthey/ RCO	• 300°F operating temperature • Requires < 50 ppm sulfur diesel • Recommended for use on 2 Stroke or very old engines that are incompatible with DPF for PM reduction	• No effect on OEM warranty • Manufacturer warranty is offered	No effect	• 1% increase in fuel consumption		• Clean unit every 15,000 hrs ($1,000 cost) • Cost negligible for BUGs as maintenance interval greater than average BUG life

Table 5. Emission Reduction Option Costs and Cost Effectiveness

Technology	Provider/ Product	Capital Cost ($) (1 MW unit)	Owner's Cost ($)	Operation & Maintenance Costs	Annual Incremental Cost ($/yr)[a]	Model Year 1986 Case		Model Year 2000 Case	
						NO_x Cost Effectiveness[b] ($/ton)	PM Cost Effectiveness[c] ($/ton)	NO_x Cost Effectiveness[b] ($/ton)	PM Cost Effectiveness[c] ($/ton)
Alternative Fuels									
Water Emulsion Fuel	Lubrizol/ PuriNOx	• $500 to purchase & install low volume fuel circulation pump • Higher if separate fuel tank needed	$200	• Sacto: 7-10 cents/gal • Bay Area: 14-17 cents/gal • 15% increased fuel use	• Sacto: $2,700 • Bay Area: $3,400	• Sacto: $9,500 • Bay Area: $11,700	• Sacto: $47,900 • Bay Area: $59,000	• Sacto: $16,600 • Bay Area: $20,300	• Sacto: $63,000 • Bay Area: $78,000
	Clean Fuel Technology/ A55			• Sacto: 12 cents/gal • Bay Area: 16 cents/gal • LA: 30 cents/gal (if delivered in 8,000 gal orders) • Smaller orders need local distributor or higher cost • 15% increased fuel use	• Sacto: $3,100 • Bay Area: $3,400 • LA: $4,700	• Sacto: $7,800 • Bay Area: $8,700 • LA: $11,900	• Sacto: $88,500 • Bay Area: $99,000 • LA: $135,000	• Sacto: $13,600 • Bay Area: $15,200 • LA: $20,800	• Sacto: $117,300 • Bay Area: $131,000 • LA: $179,000
Ultra Low Sulfur Diesel	Arco-BP/ ECD-1	None unless separate fuel tank needed	N/A	• LA/Bay Area: 5-10 cents/gal • Sacto/San Diego: 10-15 cents/gal	• LA/Bay Area: $600 • Sacto/San Diego: $1,000	N/A	• LA/Bay Area: $64,300 • Sacto/San Diego $107,000	N/A	• LA/Bay Area: $85,000 • Sacto/San Diego: $142,000
	Shell-Equilon		N/A	• Bay Area: 5-10 cents/gal • Sacramento: 10-15 cents/gal • LA/San Diego: subject to delivery costs from Martinez	• Bay Area: $600 • Sacto: $1,000	N/A	• Bay Area: $69,300 • Sacto: $107,000	N/A	• Bay Area: $85,000 • Sacto: $142,000

[a] The assumptions and methodology used to calculate annual incremental costs are discussed in Section 3.2. The evaluation assumes a 1 MW BUG operated 104 hr/yr with a fuel consumption of 75 gal/MWh.
[b] For comparison, the median price paid in California for NO_x emissions offsets in 2000 was $15,000/ton.
[c] For comparison, the median price paid in California for PM_{10} emissions offsets in 2000 was $14,000/ton.

Table 5. Emission Reduction Option Costs and Cost Effectiveness (Continued)

Technology	Provider/ Product	Capital Cost ($) (1 MW unit)	Owner's Cost ($)	Operation & Maintenance Costs	Annual Incremental Cost ($/yr)[a]	Model Year 1986 Case: NO_x Cost Effectiveness [b] ($/ton)	Model Year 1986 Case: PM Cost Effectiveness [c] ($/ton)	Model Year 2000 Case: NO_x Cost Effectiveness [b] ($/ton)	Model Year 2000 Case: PM Cost Effectiveness [c] ($/ton)
Diesel Control Technologies									
Diesel Particulate Filter	Engelhard/ DPX Soot Filter	• $30,000-$50,000 parts • 15% of parts to install	$15,000	• No maintenance (negligible) or fuel costs	$10,500	N/A	$136,000	N/A	$180,000
	Johnson Matthey/ CRT	• $60,000 parts • $2,000-$3,000 installation	$20,000	• $50/yr for maintenance • Requires ULS diesel • 0-2% increased fuel use	$15,000	N/A	$197,000	N/A	$261,000
Selective Catalytic Reduction	Engelhard/ SCR	• $90,000 parts • $35,000 installation	$40,000	• $5-$10 /MWhr urea • Annual maintenance: $1,600/yr • No additional diesel fuel costs	$30,900	$15,800	N/A	$27,400	N/A
	Johnson Matthey/ Urea SCR	• $90,000 for parts • $75,000 to install	$53,000	• $5-$10 /MWhr urea • Annual maintenance: $1,600/yr • No additional diesel fuel costs	$40,000	$21,600	N/A	$37,500	N/A
	Siemens	• $100,000 parts • $20,000-$30,000 installation	$40,000	• $3-$8/MWhr urea • Annual maintenance: $1,600/yr • No additional diesel fuel costs	$30,700	$16,000	$1,300,000	$27,800	$1,800,000
	Kleen Air	• $30,000-$40,000 for parts • $5,000 to install	$13,000	• $1.25-$6/MWhr in ammonia • Annual maintenance: $1,600/yr • No additional diesel fuel costs	$11,100	$6,300	$203,200	$11,000	$269,300

Technology	Provider/ Product	Capital Cost ($) (1 MW unit)	Owner's Cost ($)	Operation & Maintenance Costs	Annual Incremental Cost ($/yr)[a]	Model Year 1986 Case: NO_x Cost Effectiveness [b] ($/ton)	Model Year 1986 Case: PM Cost Effectiveness [c] ($/ton)	Model Year 2000 Case: NO_x Cost Effectiveness [b] ($/ton)	Model Year 2000 Case: PM Cost Effectiveness [c] ($/ton)
Diesel Control Technologies									
	Clean Diesel Technologies	• $60,000-$75,000 parts • $5,000-$10,000 installation	$24,000	• $3-$8/MWhr urea • Annual maintenance $400 • No additional diesel fuel costs	$18,100	$10,600	N/A	$18,400	N/A
Oxidation Catalyst	Engelhard/ GEN	• $10,000-$14,000 for parts • $1,000-$2,000 to install	$4,300	• No maintenance (negligible) or fuel costs	$3,100	N/A	$113,000	N/A	$149,000
	Johnson Matthey/ DOC	• $30,000 for parts • $2,000 to install	$10,000	• No maintenance costs (negligible) • 1% increased fuel use	$7,400	N/A	$408,000	N/A	$500,000
	Johnson Matthey/ RCO	• $42,000 for parts • $2,000-$3,000 installation	$14,000	• No maintenance costs (negligible) • Requires ULS diesel • 1% increased fuel use	$11,100	N/A	$304,000	N/A	$403,000

[a] The assumptions and methodology used to calculate annual incremental costs are discussed in Section 3.2. The evaluation assumes a 1 MW BUG operated 104 hr/yr with a fuel consumption of 75 gal/MWh.
[b] For comparison, the median price paid in California for NO_x emissions offsets in 2000 was $15,000/ton.
[c] For comparison, the median price paid in California for PM_{10} emissions offsets in 2000 was $14,000/ton.

3.1. Emission Control Option Description, Availability, and Implementation

3.1.1. Alternative Fuels

Two alternative fuel types were considered sufficiently developed and demonstrated to be available for near term implementation in diesel BUGs: water emulsion fuels and ultra low sulfur diesel. The technical aspects of the use of these fuels as summarized in Table 3 and Table 4. are discussed in the following.

3.1.1.1. Water Emulsion Fuels

Water emulsion fuels are produced by emulsifying deionized water into diesel fuel using a high shear pump. Proprietary additives are added to stabilize the resulting emulsion. Two suppliers of these fuels are prepared to supply their formulations to segments of the California market beginning this year, Lubrizol with their PuriNOx formulation containing 17 percent water by volume, and Clean Fuel Technology with their A55 formulation containing 13 percent water.

Water emulsion fuels reduce diesel engine NO_x emissions by lowering the peak cylinder combustion temperature thereby decreasing the production of thermal NO_x. PM emissions are reduced because the water promotes better fuel atomization via secondary atomization mechanisms (explosive water vaporization causes enhanced fuel atomization).

PuriNOx is one of the three emission control options evaluated that has achieved ARB verification. ARB has verified PuriNOx at 14 percent NO_x reduction and 63 percent PM reduction. Clean Fuel Technologies claims comparable to better NO_x reduction efficiency and comparable PM reduction efficiency, as indicated in Table 3, but these claims have not been verified.

The total amount of water emulsion fuel that could be available this summer to BUG users from the two suppliers is about 22,000 gallons of product per day from blending facilities in Sacramento (Lubrizol) and Reno, Nevada (Clean Fuel Technology). Supply could be increased by an additional 12,000 gallons per day for both the Sacramento and Los Angeles areas each by as early as July 2001 if there were sufficient demand. For comparison, operating 500 MW of BUG capacity for 104 hours (the California Independent System Operator's (CAISO) estimate of the duration of power outages during each of the summers of 2001 and 2002) would require 3.9 million gal of fuel at typical BUG fuel consumption of 75 gal/MWh. This is an average of 32,000 gal/day over the four-month summer period of June through September. These products could become available throughout the state at lower cost if either a network of local distributors/wholesalers is established or new blending facilities are built. However, either or both of these options would only be pursued by the suppliers if sufficient demand arose.

The use of water emulsion fuels can pose two major issues for BUG operators:

- The fuel has a tendency to separate into its constituent parts (diesel and water) after about two months if it is not circulated. To prevent this, the suppliers recommend installing of a small volume fuel circulation pump on each BUG's fuel storage tank sufficient to move the entire fuel tank volume once per week. With such a pump installed, the fuel can be stored for at least eight to nine months without any expected problems.

- An even more significant potential issue is the estimated 5 to 15 percent power output loss when using the lower energy content water emulsion fuels. This presents a problem for those BUGs that need to operate at their maximum power level to provide the facility's electrical demand. In some cases, it may be possible to maintain rated power output by increasing the fuel feedrate. However, neither the BUG original equipment manufacturers nor the suppliers of water emulsion fuels could specify which BUG models or model years would have a fuel feedrate adjustment capability. Accordingly, the issue of whether a BUG will be capable of maintaining maximum power output by adjusting fuel consumption rate will be highly application-specific. It may be possible to manually adjust fuel injection rates on some mechanically injected models but it is uncertain whether this can be done on all such models. Some electronically injected models may be capable of automatically increasing fuel injection rates to maintain electrical output, but others would require new software for their engine management systems, and such software generally is not available for this purpose.

In addition, the potential effects of water emulsion fuel use on engine durability is an issue that has not been completely resolved.

3.1.1.2. Ultra Low Sulfur Diesel

Current diesel fuel sold in California to meet the state's diesel fuel formulation standards contains 140 to 150 ppm sulfur. In contract, ultra low sulfur diesel fuel contains only 15 ppm sulfur. Although ultra low sulfur diesel provides only small direct reductions in NO_x and PM emissions (0 and 10 percent, respectively), it is viewed by air regulators as an enabling technology that allows the use of diesel particulate filters to provide more significant PM emission reductions.

Two suppliers in the state are currently offering ultra low sulfur diesel fuel with sulfur content of 15 ppm, Arco-BP from its refineries in Richmond and Los Angeles, and Shell-Equilon from its refinery in Martinez. The combined production from the facilities will be sufficient to fuel all the BUGs in the state as well as all other sources of expected demand for this product for both this summer and the next. The 1,000,000-gal/day supply capacity each refiner has established is substantially greater than the average 64,000 gal/day needed to operate 1,000 MW of BUG capacity for 104 hours (twice the daily average quantity needed for 500 MW noted above). By July 2001, Arco-BP will have made preliminary arrangements to have their product available throughout the state from local and wholesale distributors, but those distributors will only provide the product to the extent required by demand. Shell-Equilon has not yet made arrangements to make the product available throughout the state via local distributors/wholesalers, but will do so when and if it is necessitated by demand.

Ultra low sulfur diesel can be used in any diesel BUG with no effects on power or fuel consumption, as it has all the fuel characteristics of conventional diesel. Other than the incremental costs of this fuel, the only difference between using this fuel and conventional California diesel (140 to 150 ppm diesel) is that certain applications might require this fuel to be stored separately from other diesel products if failing to segregate them could result in the contamination of the ultra low sulfur fuel.

These fuels have not been certified or verified by ARB, but both have been granted experimental permits that allow their sale and use in the state.

3.1.2. Control Technologies

Three emission control technologies were considered sufficiently developed and demonstrated to be available for application in diesel BUGs by the summer of 2001: diesel particulate filters (DPFs), selective catalytic reduction (SCR), and oxidation catalysts. The technical aspects of the use of these technologies, as summarized in Table 3 and Table 4 are elaborated in the following.

3.1.2.1. Diesel Particulate Filters

Two suppliers offer DPFs that can achieve substantial PM reductions in the 85 to 90 percent range. The major difference between the offerings of these two suppliers is that the Engelhard's DPF is designed to operate on conventional California diesel with a sulfur content of up to 150 ppm. Johnson Matthey's product requires a diesel fuel with less than 50 ppm sulfur, which, as a practical matter, means that an ultra low sulfur diesel must be used. This notwithstanding, the ARB verification of both vendors' offerings require their use with ultra low sulfur diesel with maximum sulfur content of 15 ppm. Each supplier's product has been verified at 85 percent PM reduction for select onroad diesel engine families. The Englehard DPF has been verified for 1995 through 2001 Cummins 10.8L engines. The Johnson Matthey CRT has been verified Detroit Diesel 1998 Series 60 and 1999 and 2000 Series 50 engines.

Both suppliers have lead times that range from four to eight weeks, but units could currently be supplied in that time frame in sufficient numbers to outfit more than 1,000 diesel BUGs. Both vendors products have received anti-tampering exemptions from ARB in addition to ARB verification as noted above.

Both DPF suppliers do not recommend their use on 2-stroke engines because the DPF can become clogged, resulting in unacceptably high back pressure. This tendency to clog is the result of the lower exhaust temperatures and greater uncontrolled particulate emissions from 2-stroke engines.

DPF's will introduce some back pressure in a BUG's exhaust system. When the total back pressure of the exhaust system exceeds the back pressure limit specifications for a given BUG, a decrease in power, an increase in fuel consumption, or engine damage can result. Accordingly, both DPF suppliers custom engineer their systems for each application to ensure that the total exhaust back pressure in a given installation does not exceed the engine's specification. In those applications in which a BUG is connected to extensive exhaust piping or sound deadening equipment that already causes the maximum back pressure, some of the sound deadening equipment can be removed because a DPF can also provide some sound muffling. By designing DPF systems to each specific application, there should be no effects on a BUG's power, nor any fuel consumption increase of more than two percent.

3.1.2.2. Selective Catalytic Reduction

Five suppliers offer SCR systems for use on diesel engines. Of these, four use urea as the NO_x reducing agent as noted in Table 3; the fifth uses ammonia. The urea-based systems do not require conversion of urea to ammonia prior to injection into the engine exhaust because typical exhaust temperatures are high enough to allow the in situ decomposition of urea to ammonia and CO_2. All suppliers offer systems that can achieve 90 to 95 percent NO_x reductions. Two systems offer PM reductions as well, the Siemens urea-based system (20 to 30 percent PM reductions) and the Kleen Air ammonia-based system (50 to 70 percent PM reductions). Vendors of systems that do not offer PM reductions are considering requiring upstream DPFs in mobile applications with variable load duty cycles, but believe these will not be required in BUG applications with a more constant load duty cycle.

Over 500 urea-based SCR systems could be made available for installation during 2001 with lead times of 8 to 12 weeks. This increases to over 1,000 systems in 2002 with the same lead time range. The Kleen Air ammonia-based system will not be available until 2002.

During the initial urea-based SCR system development efforts, there were some concerns regarding these systems giving rise to N_2O emissions. However, recent studies have shown this to be more of a concern with urea-based selective non-catalytic reduction (SNCR) processes then with SCR systems. All SCR system vendors listed in Table 3 and Table 4. claim maximum ammonia slip concentrations of 10 ppm.

3.1.2.3. Oxidation Catalysts

Oxidation catalysts, designed to reduce CO and vapor phase hydrocarbon emissions, also offer some PM reduction by promoting particulate carbon burnout. Both Engelhard and Johnson Matthey offer very similar products that are designed to operate with conventional diesel fuel with sulfur content up to 500 ppm. Both provide modest decreases in PM emissions of 20 to 30 percent. The main difference between these suppliers' offerings is that Johnson Matthey's product costs about twice as much as Engelhard's comparable product. Johnson Matthey also offers an even more expensive version of its product, the RCO catalyst, that has a modified catalyst formulation and can provide greater PM emissions reductions in the 30 to 50 percent range. This catalyst formulation requires the use of diesel fuel with a maximum sulfur content of 50 ppm.

Johnson Matthey recommends the use of the RCO oxidation catalyst in 2-stroke and older, dirtier engines instead of DPFs. These engines are usually not compatible with DPF's because their higher uncontrolled PM emissions coupled with lower exhaust gas temperatures tend to clog the filters.

All of these oxidation catalysts have purchase and installation lead times of between 2 and 12 weeks, with the longer lead times applying to larger size orders such as 500 to 1,000 units. They can be installed on any diesel BUG, both 4-stroke and 2-stroke models. While the units need to be cleaned about every 15,000 hours of operation, because most BUGs are only operated 200 hr/yr or less, there are essentially no maintenance requirements.

3.1.3. Control Approach Combinations

The control approaches listed in Table 3 and Table 4 could be combined in diesel BUG applications. For example, a water emulsion fuel could be prepared with ultra low sulfur diesel, or an oxidation catalyst or DPF could be used in combination with SCR. In fact, the Kleen Air ammonia-based SCR system includes an oxidation catalyst. In addition, some technology combinations are mandated; for example, one of the Johnson Matthey oxidation catalyst offerings require the use of ultra low sulfur diesel fuel, as does the ARB verification for both the Englehard and Johnson Matthey DPFs.

These specific combinations aside, there has been little experience with technology combinations.

3.2. Emission Control Option Costs and Cost Effectiveness

3.2.1. Cost Information

The emission control option costs are summarized in Table 5.. Costs are presented in three categories in the table:

- Capital costs including parts, installation (labor), and infrastructure as needed. The capital costs include all the required engineering and design to customize the diesel retrofit system to the specific BUG to ensure compatibility and durability.

- Owner's costs including general facilities costs (owner's infrastructure-related cost such as office buildings, maintenance shops, and laboratories), engineering and home office costs (engineering, indirect, and coordination costs), and contingency costs (unexpected equipment and labor costs)

- Operation and maintenance costs including incremental fuel costs (water emulsions and ultra low sulfur diesel), reagent costs (urea and ammonia for SCR), and routine maintenance costs (cleaning and inspections)

Capital and owners costs are generally one-time expenditures while operation and maintenance costs are annual expenditures.

3.2.2. Cost Effectiveness

A key figure of merit for emission reduction options is cost effectiveness, which is the annual cost of control divided by the annual emission reduction achieved in tons pollutant pear year. To calculate the cost effectiveness, two emission reduction model cases were defined corresponding to two BUGs of different age with different uncontrolled emissions. One model case assumed a 1986 model year BUG with higher uncontrolled emissions; the second assumed a 2000 model year BUG certified to meet current ARB standards for offroad diesel engines having lower uncontrolled emissions. Table 6 summarizes the model case assumptions. The emission factors for the model year 2000 BUG are the ARB standards. The emission factors for the model year 1986 BUG were taken from the ARB OFFROAD model, as discussed in Appendix I.

Table 6. Model case assumptions for the emission reduction calculations

	Capacity MW	Annual Hours of Use	Emission Factor (g/bhp-hr)		Annual Baseline Emissions (ton)	
			NO_x	PM	NO_x	PM
Model Year 1986 BUG	1.0	104	12	0.53	2.06	0.091
Model Year 2000 BUG	1.0	104	6.9	0.40	1.19	0.069

It should be emphasized that the cost effectiveness data noted in Table 5. are for a specific model BUG deployment scenario. The particular scenario analyzed makes the following assumptions.

- CAISO forecast of 104 hr/yr (26 days at 4 hr/day) BUG operation for 2001 and 2002
- 1 MW BUG capacity
- 75 gal/MWh fuel consumption rate

Capital and owners costs were annualized using the ARB guidelines for calculating the cost effectiveness of control retrofit projects. These guidelines specify an interest rate of five percent and a project life of seven years. Annualized capital and owners costs were added to the operating and maintenance costs in Table 5. to give the total annual incremental cost ($/yr) given in the table.

summarizes the model BUG application assumptions noted above.

Table 7. Model case assumptions for the cost effectiveness calculations

Project Life (yr)	7
Diesel Fuel Cost ($/gal)	1.60
Diesel Fuel Consumption (gal/MWhr)	75
BUG Capacity (MW)	1.0
Annual Hours of Use (hr/yr)	104
Annual Fuel Use (gal/yr)	7,800
Interest Rate	5%

Table 8 summarizes the NO_x and PM emission reductions associated with each model case with the application of each control option. Percent reductions in the table are taken from Table 3. The uncontrolled emission factors for diesel engines are presented in Table 6, as noted above. The control option cost effectiveness entries in Table 5. are arrived at by dividing the annual incremental control option cost in Table 5. by the annual emission reductions in Table 8.

Table 5. shows that, in general, alternative fuel projects tend to be more cost effective than the diesel retrofit technologies. This is especially true for water emulsion fuels, which provide the most cost effective NO_x and PM emission reductions. For PM reductions alone, ultra low sulfur diesel has cost effectiveness comparable to that of the water emulsion fuels, although PM reductions are less significant.

For NO_x reductions alone, the cost effectiveness of most of the SCR processes is not significantly higher than that for the water emulsion fuels and greater NO_x reductions are achieved. The unusually attractive NO_x control costs and cost effectiveness of the Kleen Air SCR system are sufficiently out of the range of those for the other SCR processes that the Kleen Air costs cited are considered suspect. That Kleen Air will not have systems available for sale until 2002, as noted in Table 3, suggests that the Kleen Air cost estimates may be optimistic.

Table 8. Emission reductions for the evaluated emission control options

Technology	Provider/ Product	Emission Reduction Potential, %		Model Year 1986 Case Reductions[c] (tons/yr)		Model Year 2000 Case Reductions[c] (tons/yr)	
		NO_x	PM	NO_x	PM	NO_x	PM
Alternative Fuels							
Water Emulsions	Lubrizol/ PuriNOx	14%[a]	63%[a]	0.29	0.057	0.57	0.043
	Clean Fuel Technology/ A55	• Up to 15-22% for newer engines[b] • Up to 50% for older engines[b]	25-50%[b]	0.39	0.035	0.23	0.026
Ultra Low Sulfur Diesel	ARCO-BP/ECD-1	No effect	10%	0	0.009	0	0.0069
	Shell-Equilon	No effect	10%	0	0.009	0	0.0069
Diesel Control Technologies							
Oxidation Catalysts	Engelhard/ GEN	No effect	30%	0	0.027	0	0.021
	Johnson Matthey/ DOC	No effect	20%	0	0.018	0	0.014
	Johnson Matthey/ RCO	No effect	30-50%	0	0.036	0	0.027
Diesel Particulate Filter	Engelhard/ DPX Soot Filter	No effect	85%	0	0.077	0	0.058
	Johnson Matthey/ CRT	No effect	85%	0	0.077	0	0.058
Selective Catalytic Reduction	Engelhard/ SCR	95%	No effect	2.0	0	1.1	0
	Johnson Matthey/ Urea SCR	90%	No effect	1.9	0	1.1	0
	Siemens	90-95%	20-30%	1.9	0.023	1.1	0.017
	Kleen Air	80-90%	50-70%	1.8	0.055	1.0	0.041
	Clean Diesel Technologies	70-95%	No effect	1.7	0	1.0	0

[a] ARB verified.
[b] Vendor claim.
[c] 1 MW BUG operated 104 hr/yr.

4.0 Conclusions

One possible option being considered to minimize forecasted power outages in California during the summers of 2001 and 2002 is to employ the BUG capacity installed in the state when power outages are imminent. Most of this capacity is diesel engine driven, which has significantly greater emissions of NO_x and PM on a lb/MWh than any other power generation technology. Moreover, diesel PM has been declared a toxic air contaminant by ARB due to its carcinogenic characteristics.

The increased use of diesel BUGs would have less serious air quality impacts if emission controls were utilized. In this project, candidate NO_x and PM emission control options were screened to identify those with potential for near term application to mitigate the impacts of diesel BUG use. Control options considered included the use of alternative, cleaner burning fuels, and engine modification and exhaust gas treatment control technologies. Control options identified as being sufficiently developed and demonstrated to be available for near term application were subjected to detailed evaluation to establish their applicability, availability, costs, and cost effectiveness, and to identify such implementation issues as effects on BUG operation, performance, maintenance needs, and fuel consumption.

The control approach screening identified two alternative fuels and three emissions control technologies as being available for near term application. Those control approaches, and suppliers/vendors having products available for use are:

Alternative fuels

- Water diesel emulsion fuels
  - Lubrizol
  - Clean Fuel Technologies
- Ultra low sulfur diesel fuels
  - Arco-BP
  - Shell-Equilon

Control technologies

- Diesel particulate filters
  - Englehard
  - Johnson Matthey
- Selective catalytic reduction
  - Englehard
  - Johnson Matthey
  - Siemens
  - Kleen Air
  - Clean Diesel Technologies

- Oxidation catalysts
  - Englehard
  - Johnson Matthey

Emission reductions offered by these control options are as follows:

Water emulsion fuels

- 14 to 22 percent NO_x reduction
- 25 to 63 percent PM reduction

Ultra low sulfur diesel fuels

- 10 percent PM reduction

Oxidation catalysts

- 20 to 50 percent PM reductions

Diesel particulate filters

- 85 to 90 percent PM reduction (requires the use of ultra low sulfur diesel)

Selective catalytic reduction

- 70 to 95 percent NO_x reduction

Water emulsion fuels offer the most cost effective NO_x reductions, in the $8,000 to $12,000 / ton range for an older BUG with uncontrolled NO_x emissions of 12 g / bhp-hr. For PM reductions alone, ultra low sulfur diesel has cost effectiveness comparable to that of water emulsion fuels, though PM reductions are less significant. Both these fuels could be in use during 2001. One particular drawback of water emulsion fuels, however, is the 5 to 15 percent power loss associated with their use.

Given lead-time considerations, retrofit control technologies would likely not be able to affect summer 2001 emissions, but could be in place for 2002. These technologies can offer more substantial emission reductions, but are also more costly such that their cost effectiveness measures are higher than those for the alternative fuels.

Appendix I - Potential Impact of BUG Use on Current Air District NO_x and PM Emission Inventories

The statewide BUG inventory database development effort, performed as part of this project as noted in Section 1, identified 4,097 BUGs with aggregate generating capacity of 3,233 MW. The primary data sources for assembling this inventory were the air permit records maintained by the APCDs and AQMDs in the state, although supplemental data were received from Pacific Gas & Electric, Silicon Valley Power, the Los Angeles Department of Water and Power, two state agencies, and a major telecommunications company in the state. BUG inventory data were obtained from 27 of the 35 state air districts. No data were available from the Bay Area AQMD (BAAQMD) because, until recently, emergency standby engines were not required to obtain a district permit, so no permit files existed. In addition, another seven rural air districts stated that no BUGs with capacity greater the 300 kW (the focus of the inventory) existed or that no records on BUG sources were kept by the district.

Of the BUGs in the inventory, approximately 85 percent (3,424 BUGs) comprising 84 percent (2,729 MW) of the generating capacity were clearly identified by the data source as being diesel-fueled diesel (compression ignition) engine driven. As noted in Section 1, diesel engine-powered BUGs have substantially greater emissions of NO_x and PM than any other power generation technology, on a lb/MWh basis. Thus, given their substantially greater emission rates, it is possible that increased diesel BUG utilization as a power source to mitigate the number and extent of power outages in the state could have measurable impacts on regional air quality. To address this question, the emissions associated with operating all the diesel BUGs for four hours per day in each of the states air districts (except BAAQMD and the seven rural districts with no BUGs or no BUG records) was compared to the district's current total and stationary source NO_x and PM emission inventory.

To perform this comparison first requires defining an engine's NO_x and PM emission rate (tons/hr). This, in turn, requires knowledge of the engine's NO_x and PM emission factors. For these, the ARB has defined emission factors for diesel engines for use in estimating the contribution to the statewide NO_x and PM emissions of offroad mobile sources. These emission factors, included in the ARB OFFROAD emissions inventory model, are average values for diesel engines in various model years and size categories based on manufacturer data and emission test results. They are not engine make or model specific. However, they represent the best documented and most comprehensive set of emission factors and can be considered representative of the average engine population. Table I-1 summarizes these emission factors.

To estimate the emission factor for an individual diesel-fueled BUG from this compilation requires knowledge of the engine model year and rating or capacity. While engine rating or generator capacity was known for all BUGs in the inventory, engine model year was rarely given by the data source supplying information. As a consequence, it was decided to use the year the BUG's air permit application was submitted as an approximation to the engine model year. However, even this approach had limitations. Specifically, permit application date data were only available from 13 of the 27 air districts supplying inventory data. These were:

Table I - 1. Diesel engine emission factors from the ARB OFFROAD model

Engine Model Year	Emission Factor, g/hp-hr			
	NO_x		PM	
	Engines ≤750 hp	Engines >750 hp	Engines ≤750 hp	Engines >750 hp
1983 and earlier	12	12	0.53	0.53
1984 through 1987	11	11	0.53	0.53
1988 through 1995	8.17	8.17	0.38	0.38
1986 through 1999	6.90	8.17	0.40	0.38
2000 to present	6.90	6.90	0.40	0.40

- South Coast AQMD
- Sacramento Metropolitan AQMD
- Monterey Bay Unified APCD
- Yolo-Solano AQMD
- El Dorado County APCD
- Feather River AQMD
- Imperial County APCD
- Butte County APCD
- Shasta County AQMD
- Lake County AQMD
- Glenn County APCD
- Mariposa County APCD
- Colusa County APCD

For these districts, each BUG was assigned NO_x and PM emission factors from Table I-1 based on the BUG's capacity or rating and air permit application year. Each BUG's emission rate was then calculated as follows:

$$\underset{(tons/hr)}{Emission\ Rate} = \frac{Load\ Factor * \underset{(hp)}{Engine\ Rating} * \underset{(g/bhp-hr)}{Emission\ Factor}}{908{,}000\,(g/ton)}$$

and the emission rates for all diesel BUGs in the district were summed to give the total emission rate for the simultaneous operation of all diesel BUGs in the district. The load factor noted in the equation was assumed to be 0.74 in keeping with the ARB recommendation in the OFFROAD model.

For diesel BUGs in air districts that did not provide permit application dates, the age distribution of diesel BUGs in the SCAQMD was assumed to apply. The SCAQMD age distribution was considered most representative because the SCAQMD accounts for nearly half the BUGs in the inventory. The SCAQMD age distribution for the two engine size ranges in Table I-1 was applied to each of these other district's diesel BUG population to give an estimate of the number of diesel BUGs and cumulative capacity in each age and size range category.

Emission rates (ton / year) of all the diesel BUGs in the district in each age and size range were then calculated as follows:

$$\begin{matrix} Emission\ Rate \\ (tons/hr) \end{matrix} = \frac{Load\ Factor * \begin{matrix} Cumulative\ Horsepower\ in \\ Each\ Age\ and\ Size\ Range \\ (hp) \end{matrix} * \begin{matrix} Emission\ Factor \\ (g/bhp-hr) \end{matrix}}{908{,}000\,(g/ton)}$$

and the emission rates summed over all age and size ranges to give the total emission rate for the simultaneous operation of all diesel BUGs in the district. Again, a load factor of 0.74 was assumed.

Results of these emission rate calculations are summarized in Table I-2. In this table, the 13 districts with diesel BUG inventory capacity greater than 15 MW are listed individually. Population, capacity, and emission rates for the other 14 districts are combined together in another district total.

Table I - 2. Emissions of NO_x and PM by district (tons/hr)

Air District	Number of Units	Total Capacity (MW)	Emissions (ton/hr)	
			NO_x	PM
South Coast	1,935	1,627	15.94	0.79
San Diego	480	317	3.17	0.15
Sacramento Metro	285	221	2.12	0.11
San Joaquin Valley Unified	296	210	2.10	0.10
Monterey Bay Unified	112	76	0.80	0.04
Yolo/Solano	58	46	0.45	0.02
Ventura	46	40	0.40	0.02
Placer	26	34	0.34	0.02
Mojave Desert	59	33	0.33	0.02
Antelope Valley	32	18	0.18	0.01
San Luis Obispo	15	17	0.18	0.01
El Dorado	21	15	0.14	0.01
Feather River	23	15	0.15	0.01
Other Districts	86	60	0.64	0.03
Total	*3,474*	*2,729*	*26.8*	*1.3*

Using the emission rate estimates for all the BUGs in an air district given in Table I-2, the emissions associated with the operation of all the BUGs in the district for 4 hr / day can be calculated and compared to each district's current total and stationary source NO_x and PM emission inventory. Results of this comparison to district total inventories are summarized in Table I-3. The data in Table I-3 show that operating all diesel BUGs for 4 hr / day would cause NO_x emissions that equal over two percent of a district's current total NO_x emissions. This occurs for 10 of the 13 districts noted in the table. For six of the districts, BUG emissions would total four percent or more of the district's current inventory. This impact is not insignificant. Similarly, BUG PM emissions equal over 1.5 percent of the district's current total PM emissions inventory for 8 of the 13 districts listed in the table.

Table I - 3. Emissions of NO_x and PM by district compared to the district's current daily total emissions inventory

	NO_x (tons/day)			PM (tons/day)		
Air District	BUG Emissions, 4 hr/day Operation	District Total Inventory	Percentage of Inventory	BUG Emissions, 4 hr/day Operation	District Total Inventory[a]	Percentage of Inventory
South Coast	63.7	1,237.3	5.1%	3.16	75.3	4.2%
San Diego	12.7	236.4	5.4%	0.62	20.0	3.1%
Sacramento Metro	8.5	112.0	7.6%	0.42	6.0	7.0%
San Joaquin Valley Unified	8.4	598.0	1.4%	0.41	96.0	0.4%
Monterey Bay Unified	3.2	48.7	6.6%	0.15	9.0	1.7%
Yolo/Solano	1.8	73.0	2.5%	0.09	9.7	0.9%
Ventura	1.6	75.7	2.1%	0.08	5.0	1.6%
Placer	1.4	29.6	4.7%	0.07	4.1	1.7%
Mojave Desert	1.3	154.0	0.8%	0.07	21.0	0.3%
Antelope Valley	0.7	31.7	2.2%	0.04	2.0	2.0%
San Luis Obispo	0.7	31.1	2.3%	0.03	5.6	0.5%
El Dorado	0.6	15.1	4.0%	0.03	1.9	1.6%
Feather River	0.6	24.0	2.5%	0.03	6.7	0.4%
Other Districts	2.6	293.9	0.9%	0.13	67.6	0.2%

[a]For PM, daily inventory includes all sources except for natural and anthropogenic dust producing processes.

Perhaps a better measure of the potential impact of increased diesel BUG operation is to make the comparison to district stationary source emissions inventories. This comparison is presented in Table I-4. The data in this table show that operating all diesel BUGs for 4 hr / day could cause NO_x emissions that equal more significant fractions of the district's current daily emissions from all other stationary sources. For six of the 13 individually listed districts, BUG emissions could represent 40 percent or more of the districts' current stationary source emissions. In fact, for the Sacramento Metropolitan AQMD, diesel BUG emissions for four hours a day operation would total 144 percent of the district's current stationary source emissions.

Table I - 4. Emissions of NO_x and PM by district compared to the district's current daily stationary source emissions inventory

Air District	NO_x (tons/day)			PM (tons/day)		
	BUG Emissions, 4 hr/day Operation	Stationary Source Inventory[a]	Percentage of Inventory	BUG Emissions, 4 hr/day Operation	Stationary Source Inventory[a]	Percentage of Inventory
South Coast	63.7	149.6	43%	3.16	32.63	10%
San Diego	12.7	21.9	58%	0.62	8.68	7.1%
Sacramento Metro	8.5	5.9	144%	0.42	2.15	20%
San Joaquin Valley Unified	8.4	197.2	4.3%	0.41	79.6	0.5%
Monterey Bay Unified	3.2	16.9	19%	0.15	7.62	2.0%
Yolo/Solano	1.8	12.9	14%	0.09	5.38	1.7%
Ventura	1.6	17.0	9.4%	0.08	2.53	3.2%
Placer	1.4	2.4	57%	0.07	3.04	2.3%
Mojave Desert	1.3	102.1	1.3%	0.07	19.2	0.4%
Antelope Valley	0.7	1.4	53%	0.04	0.9	4.4%
San Luis Obispo	0.7	4.5	15%	0.03	4.37	0.7%
El Dorado	0.6	1.3	46%	0.03	1.21	2.5%
Feather River	0.6	3.9	15%	0.03	5.78	0.5%
Other Districts	2.6	72.0	3.6%	0.13	54.25	0.2%

[a]For NO_x, daily inventory includes all stationary sources. For PM, daily inventory includes stationary sources except for natural and anthropogenic dust producing processes.

Diesel BUG PM emissions represent less significant fractions of districts' stationary source PM. The maximum fraction, at 20 percent, is also for the Sacramento Metropolitan AQMD. However, specific locations could be significantly affected by diesel BUG operation, especially considering the carcinogenic nature of diesel PM.

The potential significance of the air quality effects of increased diesel BUG operation to address short-term power shortages points to the need to evaluate means of mitigating their emissions. This evaluation is the subject of the main body of this report.